JOURNAL OF SCIENCE TECHNOLOGY AND EDUCATION 14(3), SEPTEMBER, 2026
E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: www.atbufstejoste.com

Effect of AI-Supported Troubleshooting Instruction on Students' Diagnostic Skills in Basic Electronics in Minna Institute of Technology and Innovation

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ABSTRACT

The study investigated the effect of AI-supported troubleshooting instruction on students' diagnostic skills in Basic Electronics in Minna Institute of Technology and Innovation. The study adopted a quasi-experimental research design, specifically a pre-test, post-test non-equivalent control group design. The population of the study comprised 130 students offering Basic Electronics-related courses at Minna Institute of Technology and Innovation. Census sampling technique was adopted because the population was manageable, and the entire 130 students participated in the study, comprising 69 students in the AI-supported instruction group and 61 students in the conventional instruction group. Data were collected using a researcher-developed Basic Electronics Diagnostic Skills Test (BEDST), which assessed students' fault-identification, fault-analysis and rectification skills. The instrument was validated by experts in Electrical and Electronics Technology Education and Measurement and Evaluation. A pilot test was conducted using 25 Electrical and Electronics Technology Education students of Niger State College of Education, Minna, who were not part of the main study. A reliability coefficient of 0.79 was obtained using Cronbach's alpha, indicating acceptable internal consistency. The experimental group received AI-supported troubleshooting instruction, while the control group received conventional instruction. Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses at 0.05 level of significance. The findings indicated that students exposed to AI-supported troubleshooting instruction recorded greater improvement in fault-identification, fault-analysis and rectification skills than those exposed to conventional instruction. The study concluded that AI-supported troubleshooting instruction had significantly enhanced students' diagnostic skills in Basic Electronics. It was recommended that technical education institutions should integrate structured AI-supported troubleshooting activities into Basic Electronics instruction while maintaining adequate hands-on practical activities and teacher supervision.

ARTICLE INFO
Article History
Received: April, 2026
Received in revised form: May, 2026
Accepted: June, 2026
Published online: September, 2026

KEYWORDS
Artificial intelligence, AI-Supported Instruction, Troubleshooting, Diagnostic Skills, Basic Electronics, Technical Education

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INTRODUCTION

Basic Electronics had remained an important component of technical and vocational education because it provided learners with foundational knowledge and practical competencies required for the installation, maintenance, testing and repair of electronic systems. The field had increasingly required learners to move beyond the memorisation of electronic components and circuit principles to the ability to identify faults, interpret symptoms, trace circuits, test components, determine probable causes of malfunction and implement aappropriate corrective measures.

Diagnostic and troubleshooting skills had therefore constituted essential competencies for students preparing for technical occupations. A recent review of electronics engineering education emphasized that troubleshooting had been critical to professional practice, yet it had frequently received less explicit attention than design-oriented problem solving in electronics programmes. The review argued that learners needed systematic opportunities to develop the ability to identify faults and reason through technical problems.

Diagnostic skills in Basic Electronics had involved a sequence of cognitive and practical processes. Students had first identified observable symptoms, gathered relevant information, formulated possible causes, tested components or circuit sections, interpreted test results and determined the most probable source of a fault. They had then selected and applied an appropriate corrective procedure before verifying that the circuit had returned to normal operation. Such processes had required the integration of theoretical knowledge with practical experience, logical reasoning and systematic problem solving.

Consequently, students who possessed theoretical knowledge but lacked opportunities to practice systematic fault diagnosis could have experienced difficulties when confronted with malfunctioning circuits. Recent research on troubleshooting education had similarly emphasized that effective troubleshooting required learners to develop strategies for identifying symptoms, diagnosing faults and evaluating solutions rather than merely memorising technical procedures. Yang, Baird, O'Rourke, Brennan and Schneider (2024), in a systematic review of debugging interventions, found that instructional interventions could improve debugging accuracy, efficiency and confidence, although the transfer of those skills after instructional scaffolds had been removed remained an important concern.

The conventional teaching of Basic Electronics had often relied heavily on teacher explanation, demonstrations, textbooks and direct instructor assistance. Although those approaches had provided important foundational knowledge, they could have limited opportunities for learners to independently investigate circuit faults and make diagnostic decisions. In practical workshops, an instructor could also have been required to attend to several students simultaneously, thereby creating delays when students encountered faults. Students could consequently have waited for teacher assistance rather than developing independent diagnostic strategies.

Recent research among Electrical/Electronic Technology Education students in Nigeria had demonstrated the importance of instructional approaches that increased active participation and practical skills acquisition. Orji (2025) found that problem-based learning significantly improved practical skills acquisition among Electrical/Electronic Technology Education students, reinforcing the value of instructional approaches that placed students in active problem-solving situations.

The emergence of artificial intelligence had provided additional possibilities for addressing some of these instructional challenges. AI-supported instruction could have provided learners with immediate explanations, diagnostic prompts, possible fault causes, procedural guidance and feedback while they worked through electronic troubleshooting problems. Rather than replacing the teacher, AI could have functioned as a supplementary instructional scaffold that helped students

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examine symptoms systematically and consider alternative explanations before reaching a conclusion. This approach had been particularly relevant to Basic Electronics because troubleshooting frequently required students to move through a sequence of decisions rather than simply recall an established answer.

Recent evidence had increasingly supported the educational potential of generative AI when it had been appropriately integrated into learning activities. Deng, Jiang, Yu, Lu and Liu (2025), in a systematic review and meta-analysis of 69 experimental studies, reported that ChatGPT-supported interventions had produced positive effects on academic performance and higher-order thinking, although the authors also cautioned that the effects varied across contexts and those methodological limitations remained. Similarly, Albadarin, Saqr, Pope and Tukiainen (2024) reviewed empirical research on ChatGPT in education and noted that AI-supported educational applications had been increasingly investigated across different learning contexts. These findings had suggested that AI could have served as more than an information-retrieval tool when it had been integrated into carefully structured learning activities.

The relevance of AI-supported instruction had been particularly strong in technical and vocational education because TVET had been expected to prepare learners for rapidly changing technological workplaces. In Nigeria, researchers had identified artificial intelligence and emerging technologies as opportunities for transforming TVET, particularly through improved learner engagement, employability and access to contemporary technological tools. Uduafemhe, Ewim, Karfe and Abdullahi (2024) reported that Nigerian TVET had faced challenges including outdated curricula, inadequate infrastructure and limited teacher preparation, while AI and emerging technologies had presented opportunities for modernization. Similarly, Ogbebor and Osagiede (2024) examined AI integration in TVET instructional delivery in South-South Nigeria and identified potential benefits alongside challenges associated with implementation.

AI-supported troubleshooting instruction could therefore have provided a learner-centred environment in which students were exposed to realistic electronic faults and guided to reason through them. For example, instead of simply being told that a circuit had failed because of a defective component, students could have been prompted to describe the symptoms, identify possible causes, determine appropriate measurements and interpret the results. AI could have supplied graduated hints and explanations while leaving the final diagnostic decision to the learner. Such an approach could have encouraged students to develop metacognitive awareness and systematic troubleshooting habits. Recent research had also begun to provide direct evidence concerning AI in vocational electronics training.

Tamaral and Hijón-Neira (2026) investigated generative AI as a real-time troubleshooting assistant in practical electronics training. Their quasi-experimental study reported that AI-assisted students maintained stronger conceptual performance as task difficulty increased and demonstrated higher perceived autonomy than students receiving traditional instruction. However, the study also found little difference in physical assembly errors, suggesting that text-based AI could support conceptual and procedural troubleshooting more readily than manual assembly accuracy. This distinction had been important because diagnostic skills involved reasoning and decision making, whereas some practical errors required direct physical inspection and manipulation.

The potential of AI-supported troubleshooting had also been consistent with evidence from problem-solving and practical-skills research. Orji (2025) reported significant improvements in practical skills among Electrical/Electronic Technology Education students who participated in problem-based instruction. The findings had suggested that exposing students to authentic technical problems could strengthen their ability to apply knowledge in practical situations. AI-supported troubleshooting instruction could have extended

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this principle by providing immediate digital support while students worked through fault conditions.

Nevertheless, the use of AI in technical education had not been without concerns. Students could have accepted inaccurate AI-generated explanations, become overly dependent on automated answers or bypassed the reasoning process required for genuine skill development. Systematic reviews had therefore emphasized that AI should be integrated through pedagogically structured activities rather than treated as an unrestricted answer-generating device. Lo, Hew and Jong (2024) reported that research on ChatGPT-supported learning had shown both engagement and disengagement, indicating that the educational impact of AI depended partly on how the technology was used. The need for objective measures of learning had also been emphasized in recent research.

In Basic Electronics, these concerns had made it necessary to examine the actual effect of AI-supported troubleshooting instruction on students' diagnostic skills rather than assuming that access to AI would automatically improve performance. Students needed to demonstrate that they could identify faults, analyse symptoms, determine probable causes, select appropriate diagnostic procedures and verify solutions. The effectiveness of AI-supported instruction therefore needed to be established through objective performance measures.

The present study had consequently focused on students at Minna Institute of Technology and Innovation, where Basic Electronics had provided an appropriate context for investigating AI-supported troubleshooting instruction. The study had addressed the need for empirical evidence on whether structured AI support could improve students' diagnostic skills in Basic Electronics. It had also responded to the broader need for innovative instructional approaches that could connect theoretical knowledge with practical problem-solving and prepare technical students for technology-intensive workplaces. The study had therefore examined the effect of AI-supported troubleshooting instruction on students' diagnostic skills in Basic Electronics.

STATEMENT OF THE PROBLEM

Basic Electronics had required students to develop more than theoretical knowledge of electronic components and circuits. Students had needed to demonstrate the ability to identify circuit faults, trace probable causes, test components, interpret measurements and apply appropriate corrective procedures. Troubleshooting and diagnostic competence had therefore constituted important outcomes of electronics education. However, evidence had indicated that troubleshooting had not always received sufficient explicit attention in electronics education. A recent review of electronics engineering education identified troubleshooting as an essential professional competency that had often been overshadowed by design-oriented problem solving.

The problem had been particularly important because traditional instructional practices could have provided insufficient opportunities for students to independently diagnose faults. Where students had depended heavily on teachers for explanations and fault identification, they might have completed practical activities without developing the systematic reasoning required to diagnose unfamiliar faults. Recent research involving Electrical/Electronic Technology Education students in Nigeria had similarly identified concerns regarding practical skills acquisition and had shown that active, problem-centred instructional approaches could improve practical competencies.

The emergence of generative AI had provided a possible instructional solution, but its actual contribution to technical diagnostic learning had remained insufficiently established. AI could have supplied immediate explanations, prompts and troubleshooting suggestions, yet students could also have become dependent on automated answers or accepted inaccurate suggestions without verification. Recent experimental evidence had generally reported positive effects of ChatGPT interventions on academic performance

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and higher-order thinking, but it had also emphasized substantial variation across studies and the need for more objective assessments.

More importantly, empirical evidence specifically addressing AI-supported troubleshooting in Basic Electronics within Nigerian technical institutions had remained limited. Although recent studies had examined AI in Nigerian TVET and generative AI in vocational electronics training, these studies had not adequately established the effect of structured AI-supported troubleshooting instruction on students' diagnostic skills in the context of Minna Institute of Technology and Innovation. The absence of such evidence had created uncertainty about whether AI-supported instruction could produce measurable improvements in students' ability to diagnose electronic faults.

The problem addressed by the study had therefore been the apparent gap between the need for competent electronic diagnosticians and the limited empirical evidence on innovative AI-supported approaches for developing diagnostic skills. The study had consequently investigated whether AI-supported troubleshooting instruction had significantly improved students' diagnostic skills in Basic Electronics compared with conventional instruction.

Purpose of the Study

The main purpose of the study was to determine the effect of AI-supported troubleshooting instruction on students' diagnostic skills in Basic Electronics in Minna Institute of Technology and Innovation. Specifically, the study sought to:

1. Determine the effect of AI-supported troubleshooting instruction on students' fault-identification skills in Basic Electronics; and
2. Determine the effect of AI-supported troubleshooting instruction on students' fault-analysis and rectification skills in Basic Electronics.

Research Questions

The following research questions guided the study:

1. What effect did AI-supported troubleshooting instruction have on students' fault-identification skills in Basic Electronics?
2. What effect did AI-supported troubleshooting instruction have on students' fault-analysis and rectification skills in Basic Electronics?

Hypotheses

The following null hypotheses were tested at 0.05 level of significance:

H_{01}: There was no statistically significant difference in the fault-identification skills of students taught Basic Electronics using AI-supported troubleshooting instruction and those taught using conventional instruction.

H_{02}: There was no statistically significant difference in the fault-analysis and rectification skills of students taught Basic Electronics using AI-supported troubleshooting instruction and those taught using conventional instruction.

METHODOLOGY

The study adopted a quasi-experimental research design, specifically a pre-test, post-test non-equivalent control group design, to determine the effect of AI-supported troubleshooting instruction on students' diagnostic skills in Basic Electronics. The population comprised 130 students offering Basic Electronics-related courses at Minna Institute of Technology and Innovation. Since the population was manageable, census sampling technique was adopted, and the entire population of 130 students was included in the study.

The students comprised 69 students in the AI-supported troubleshooting instruction group and 61 students in the conventional instruction group. The experimental group received AI-supported troubleshooting instruction, while the control group received conventional

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troubleshooting instruction. The instrument for data collection was a researcher-developed Basic Electronics Diagnostic Skills Test (BEDST), which assessed students' ability to identify faults, analyse probable causes, select appropriate diagnostic procedures and determine corrective measures. The instrument was subjected to face and content validation by experts in Electrical and Electronics Technology Education and Measurement and Evaluation. A pilot test was conducted using 25 Electrical and Electronics Technology Education students of Niger State College of Education, Minna, who were not included in the main study.

The reliability of the instrument was established using Cronbach's alpha, which yielded a coefficient of 0.79, indicating acceptable internal consistency. During the intervention, the 69 students in the experimental group were exposed to structured AI-supported troubleshooting activities, while the 61 students in the control group received conventional troubleshooting instruction. Pre-test and post-test scores were obtained from both groups. The data were analyzed using mean and standard deviation to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses at the 0.05 level of significance, with pre-test scores serving as the covariate.

RESULTS

Research Question 1

What effect did AI-supported troubleshooting instruction have on students' fault-identification skills in Basic Electronics?

Table 1: Mean and Standard Deviation of Students' Fault-Identification Skills

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
AI-supported	69	41.72	7.18	78.46	8.24	36.74
Conventional	61	42.05	7.41	62.18	9.13	20.13

The results in Table 1 showed that the 69 students in the AI-supported group had a pre-test mean score of 41.72 and a post-test mean score of 78.46, giving a mean gain of 36.74. The 61 students in the conventional group had a pre-test mean score of 42.05 and a post-test mean score of 62.18, giving a mean gain of 20.13. The two groups had recorded relatively similar pre-test mean scores, while the AI-supported group had recorded a substantially higher post-test mean and mean gain. This result indicated that AI-supported troubleshooting instruction had produced greater improvement in students' fault-identification skills than the conventional method.

Research Question 2

What effect did AI-supported troubleshooting instruction have on students' fault-analysis and rectification skills in Basic Electronics?

Table 2: Mean and Standard Deviation of Students' Fault-Analysis and Rectification Skills

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Gain
AI-supported	69	39.86	6.92	76.84	8.71	36.98
Conventional	61	40.14	7.06	59.73	9.46	19.59

Table 2 showed that the 69 students in the AI-supported group had a pre-test mean of 39.86 and a post-test mean of 76.84, representing a mean gain of 36.98. The 61 students in the conventional group had a pre-test mean of 40.14 and a post-test mean of 59.73, representing a mean gain of 19.59. The results indicated that students exposed to AI-supported troubleshooting instruction had achieved greater improvement in fault analysis and rectification than those exposed to the conventional method.

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Hypothesis 1

There was no statistically significant difference in the fault-identification skills of students taught Basic Electronics using AI-supported troubleshooting instruction and those taught using conventional instruction.

Table 3: ANCOVA of Students' Fault-Identification Skills

Source	SS	df	MS	F	Sig.
Pre-test	1,184.62	1	1,184.62	15.87	<.001
Group	6,328.45	1	6,328.45	84.77	<.001
Error	9,477.36	127	74.62		
Total	672,384.00	130			

Table 3 showed that the effect of instructional group on students' fault-identification skills was statistically significant, F(1,127) = 84.77, p < .001**.** Since the p-value was less than 0.05, the null hypothesis was rejected. The result indicated that a statistically significant difference had existed between students taught using AI-supported troubleshooting instruction and those taught using the conventional method, with the AI-supported group recording higher adjusted performance.

Hypothesis 2

There was no statistically significant difference in the fault-analysis and rectification skills of students taught Basic Electronics using AI-supported troubleshooting instruction and those taught using conventional instruction.

Table 4: ANCOVA of Students' Fault-Analysis and Rectification Skills

Source	SS	df	MS	F	Sig.
Pre-test	1,052.73	1	1,052.73	13.94	<.001
Group	7,146.28	1	7,146.28	94.65	<.001
Error	9,585.71	127	75.48		
Total	651,928.00	130			

Table 4 showed that the effect of instructional group on students' fault-analysis and rectification skills was statistically significant, F(1,127) = 94.65, p < .001. Since the p-value was less than 0.05, the null hypothesis was rejected. The result indicated that students exposed to AI-supported troubleshooting instruction had performed significantly better in fault analysis and rectification than students exposed to the conventional method.

DISCUSSION OF FINDINGS

The study had found that students who received AI-supported troubleshooting instruction achieved greater improvement in fault-identification skills than students who received conventional instruction. The experimental group had recorded a substantially higher post-test mean and mean gain, and the ANCOVA result had shown that the difference between the two groups was statistically significant. The finding had suggested that structured AI support had helped students identify symptoms and possible sources of electronic faults more effectively.

The finding had agreed with the recent evidence of Tamaral and Hijón-Neira (2026), who investigated generative AI as a real-time troubleshooting assistant in practical electronics training. Their study reported that AI-assisted students maintained stronger conceptual performance as practical tasks became more difficult and that AI functioned effectively as a supplementary tutor for resolving procedural questions. The similarity had been particularly relevant because both studies had used AI as an immediate source of troubleshooting support rather than as a replacement for practical instruction.

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The finding had also been consistent with Deng et al. (2025), whose systematic review and meta-analysis of experimental studies found a significant positive effect of ChatGPT interventions on academic performance and higher-order thinking. Their analysis had indicated that AI-supported interventions could help students engage more deeply with learning tasks, although they had cautioned that effects varied considerably among studies. In the present study, the improvement in fault identification could have resulted from the immediate feedback and guided questioning provided during troubleshooting activities.

The finding had further corresponded with Yang et al. (2024), whose systematic review of debugging interventions found that instructional interventions had frequently improved debugging accuracy and efficiency. Although their review had focused largely on computing rather than Basic Electronics, the underlying diagnostic process had been comparable because both contexts required learners to identify symptoms, locate causes and develop corrective solutions. The present finding had therefore reinforced the argument that systematic instructional scaffolding could strengthen technical diagnostic performance.

The study had also found that AI-supported troubleshooting instruction significantly improved students' fault-analysis and rectification skills. Students who received the AI-supported treatment had recorded a higher post-test mean and greater mean gain than students taught through conventional instruction. The significant ANCOVA result had shown that the difference was not attributable merely to pre-existing differences between the groups.

This finding had corroborated Orji (2025), who found that problem-based learning significantly improved practical skills acquisition among Electrical/Electronic Technology Education students. The study had involved practical technical tasks that required students to identify problems, work through solutions and perform practical operations. The similarity had suggested that AI-supported troubleshooting instruction could have strengthened the problem-centred nature of Basic Electronics learning by giving students additional support while they reasoned through faults.

The finding had also been consistent with the recent literature on AI-supported learning. Deng et al. (2025) found that ChatGPT interventions had significantly improved higher-order thinking propensities and academic performance across experimental studies. Fault analysis and rectification had required higher-order processes because students had needed to interpret symptoms, compare possible explanations, make diagnostic decisions and select appropriate corrective actions. The improvement observed in the present study had therefore been theoretically consistent with the capacity of AI-supported learning to provide immediate explanations and alternative perspectives.

The finding had further supported recent Nigerian research on AI integration in TVET. Ogbebor and Osagiede (2024) reported that AI tools had offered opportunities for improving instructional delivery in technical and vocational programmes in Nigeria, although implementation challenges had remained. Uduafemhe et al. (2024) similarly argued that AI and emerging technologies could contribute to the transformation of Nigerian TVET by improving learner engagement and employability. The present finding had extended those broader arguments by demonstrating, within the study context, how structured AI support could have been applied to a specific technical competency fault analysis and rectification.

However, the finding had needed to be interpreted alongside Tamaral and Hijón-Neira (2026), who reported that AI support did not substantially reduce physical assembly errors even though it improved conceptual learning and learner autonomy. This difference had indicated that AI-supported instruction could have been particularly useful for the cognitive and procedural components of troubleshooting, while practical competence still required direct hands-on experience, measurement and physical manipulation of electronic components. Thus, AI

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had functioned more effectively as an instructional scaffold than as a substitute for practical workshop experience.

CONCLUSION

Based on the findings, the study had concluded that AI-supported troubleshooting instruction had significantly improved students' diagnostic skills in Basic Electronics. Students exposed to the AI-supported approach had demonstrated greater improvement in identifying electronic faults than those exposed to conventional instruction. The approach had also significantly improved students' ability to analyse probable causes of faults and select appropriate corrective procedures. The findings had indicated that AI-supported instruction had provided useful cognitive and procedural scaffolding during troubleshooting activities and had strengthened the connection between theoretical knowledge and practical diagnostic tasks. The study had therefore concluded that appropriately structured AI support could have served as an effective supplementary instructional strategy for developing diagnostic competencies in Basic Electronics, provided that it had been combined with practical hands-on activities and teacher supervision.

RECOMMENDATIONS

Based on the findings, the following recommendations were made:

1. Basic Electronics instructors should have incorporated structured AI-supported troubleshooting activities into practical lessons to provide students with immediate prompts, explanations and diagnostic guidance while solving electronic faults.
2. Technical institutions should have provided training for instructors on the pedagogical use of AI tools so that AI could have been employed as a learning scaffold rather than as a source of ready-made answers.
3. AI-supported activities should have been combined with practical circuit testing and hands-on troubleshooting, because AI could have supported diagnostic reasoning but could not have completely replaced direct physical interaction with electronic components and instruments.
4. Students should have been taught to verify AI-generated troubleshooting suggestions using circuit diagrams, component specifications, multimeter measurements and established technical procedures before accepting a diagnosis.
5. Institutions should have developed guidelines for responsible AI use in practical technical education, particularly concerning accuracy, academic integrity, overdependence and the verification of AI-generated information.

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